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Effect of Tillage on Double-cropped Flax/Cotton Production and Fiber Properties

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Abstract

There currently are no data on using reduced tillage for flax (*Linum usitatissimum* L.) production when double-cropped after cotton (*Gossypium hirsutum* L.) in the southeastern USA. This study evaluated how tillage and subsoiling influenced double-cropped flax and cotton productivity and quality under conditions in the southeastern USA. An irrigated study on a loamy sand soil (Eunola loamy sand) was conducted beginning in spring 2001 through spring 2003. Treatments evaluated in both crops were subsoiling (subsoiled to 30-cm or none) and tillage (chisel plow to 20-cm plus disking, disking only, and no tillage). Standard fiber test methods were used to evaluate treatment effects on fiber properties. Subsoiling increased the cotton and flax yield. Cotton yields were not influenced by tillage treatment while flax dry plant matter yields were greater for chisel and disk treatments compared with the no-tillage treatments. Fiber properties, cotton micronaire, fiber length, and fiber length uniformity, and flax fiber strength were impacted by tillage. Our results indicate that for this double-crop system, no tillage with subsoiling is a viable practice for cotton but further research is needed to improve flax productivity with this management practice.

Introduction

Flax is a dual-purpose crop, producing both seed and fiber. Flax is used by the paper (13), composite (23), and textile (24) industries and the seed is utilized to produce industrial (8) and nutritional (20) oils. Flax is a summer oilseed crop grown in the northern Midwestern USA and Canada. Varieties used for fiber differ from those grown for seed. Compared to seed flax, fiber flax plants are taller, have fewer branches, produce more fiber, have lower oilseed content, and produce less seed (2).

Cool and moist weather in the southeastern USA allow this crop to be grown in winter (15). Production of flax as a winter crop may allow the same fields to be utilized for cotton during the summer and flax fiber during the winter. Potentially, this will provide textile manufactures two fiber crops in one year. Typically, soybean [*Glycine max* (L.) Merr.] and small grains are double cropped in the southeast. Double cropping cotton and flax for fiber may provide an economic alternative, providing a feasible production scheme can be developed. In order to accomplish this, physical properties of the flax fibers in the southeastern USA must be known.

In the southeastern US and many other areas, numerous acres have been converted to reduced tillage (RT) management because it reduces erosion, evaporation, and production costs. RT also improves soil tilth and structure (25). Good soil structure is an essential requirement for good flax growth in soils where root penetration can be prevented by very hard compacted soil (24). Firm and moist seedbeds of untilled fields may be an advantage to flax seedling establishment. In Canada, on brown/dark brown and black/dark grey/grey soil zones across the prairies, seed flax grows well in RT with flax yields that equal or surpass conventional-tilled (CT) plots (9,17,19). Currently, there exists no data on RT of flax in the southeastern US. Soils in the southeastern Coastal Plain typically are coarse textured with shallow compacted soil layers that limit root depth and reduce plant water availability. Subsoiling is recommended to increase available water and reduce yield reductions in times of drought (10).

For cotton, tillage can affect fiber quality and yield inconsistently as an indirect response because of shifts in the growing season relative to conventional tillage (22). In the Coastal Plain area, management systems with no surface tillage did not influence fiber strength (7). Subsequently, Bauer and Frederick (6) found higher length uniformity with conservation tillage than with disk tillage. Bauer and Frederick (6) also found that tillage management influenced fiber properties at specific canopy positions. Cost differentials are not huge between different management systems; however, higher cotton market prices would increase practice differences (12).

More cotton is shipped overseas with improvements in cotton quality potentially improving the export market. The value of cotton can be expressed in terms of cents per kg with the US average Daily Spot Cotton Quotations (27). The current base quality of cotton is a color grade of 41, leaf grade of 4, two micronaire ranges covering 3.5 to 3.6 and 4.3 to 4.9, staple length 34 (length 26.7 to 27.2 mm), strength of 26.5 to 28.4 grams/tex, uniformity of 81%, and no extraneous matter (27). Cotton bale fiber qualities can be found in tables within the Daily Spot Cotton Quotations to locate premiums or discounts schedules for respective cotton bales. These premiums or discounts are then respectively added or subtracted from the base price (*personal communication*, B. Meredith).

The impact of tillage or sub-soiling on the quality or variability of flax fiber quality in the southeast is not known. The purpose of this study was to evaluate flax fiber properties with various tillage and subsoiling techniques under southeastern US conditions when double cropped with cotton. Standard fiber test methods were used to evaluate crop production effects on fiber properties. These standard test methods have recently been adopted by ASTM International; however, no organization currently exists to provide standardization and grading for the marketing of flax fiber at its appropriate value. Similar to cotton, flax fiber that is uncontaminated and consistently higher in quality will sell at a higher premium than poor quality fiber.

Field Experiments

A cotton-flax double crop study was conducted on a Eunola loamy sand (fine-loamy, siliceous, thermic Aquic Hapludult) from 2001-2003 at the Pee Dee Research and Education Center located near Florence, SC (34°17'N, 79°41' W). Plots were irrigated with subsurface drip irrigation with laterals 2 m apart (Geoflow Rootguard, Corte Madera, CA). Laterals had in-line labyrinth emitters 0.6 m apart that delivered water at 1.7 liter/h.

Tillage treatments were: (i) no tillage (NT); (ii) disking the soil twice to a depth of 15 cm then smoothed with a harrow equipped with s-shaped tines and rolling baskets (D2H); and (iii) chisel plowing with a 2.1-m-wide, seven-shank chisel to a depth of 20 cm, disked twice to a depth of 15 cm and then smoothed with a harrow equipped with s-shaped tines and rolling basket (CD2H).

For each of these three tillage systems, sub-soiling was either not done or performed to a depth of 30 cm with straight 45° forward angled subsoiler shanks spaced 97 cm apart. Treatments were arranged as a randomized complete block with four replications. Plots were 15 m long and 7.7 m wide.

Tillage and subsoiling treatments were performed before planting cotton on 31 May 2001 and 14 May 2002. Cotton (variety DP-458BRR) was planted in 97-cm-wide rows at 13 plants per meter of row on 4 June 2001 or 15 May 2002 and managed using standard fertility/weed management protocols. Cotton was harvested on 7 November 2001 and 28 October 2002 with a two-row spindle picker. Cotton was saw-ginned on a laboratory-scale gin to determine lint yield and fiber qualities were determined using HVI techniques (5). Color and trash measurements from laboratory-scale gins do not relate well to commercially ginned lint.

'Laura' flax was grown as a winter crop. In 2001-2002, fertilizer was applied on 13 November at a rate of 22 kg N, 66 kg P_2O_5, and 100 kg K_2O/ha. Tillage treatments were performed on 19 November with sub-soiling performed on 20 November. Flax was planted in 20-cm-wide rows on 27 November with a no-till drill (Model 750, Deere & Company, Moline, IL) at a seeding rate of 112 kg/ha. On 15 February, all plots received N at 69 kg/ha. Flax was irrigated with 6 mm of water on 19 April and 22 April. Flax was cut with a drum mower on 1 May at the onset of flowering. Dried flax stalks were harvested on 8 May using a rectangle baler. Sub-samples of the straw were dried at 70°C for 48 h, and weighed.

In 2002-2003, $CaMgCO_3$ at 1122 kg/ha was applied on 30 October. On that same date 22 kg N, 66 kg K_2O, and 100 kg P_2O_5 per ha were applied. Tillage and sub-soiling treatments were performed on 31 October and flax was subsequently planted in 20 cm wide rows on 4 November. On 15 February, all plots received N at 74 kg/ha. At the onset of flowering for straw yield, flax was hand harvested on 7 May. Sub-samples of the straw were dried at 70°C for 48 h, and weighed.

Flax Fiber Processing

Flax stalks were collected and transported to the Cotton Quality Research Station, ARS-USDA, Clemson, SC, where the bast fibers were released from the stem by dew-retting, a process in which indigenous fungi and bacteria colonize and partially decompose the flax stems. Stalks were dew-retted until the fibers appeared silver and separated easily from the stem. Dew-retted stalks were processed at USDA Flax Fiber Pilot Plant (Flax-PP) using a process previously described by Akin et al. (1). Flax-PP fiber yield is the percent of fiber separated from the dew-retted flax stalks.

Fibers cleaned at Flax-PP maintained their length through processing and required cottonizing (fiber length and fineness comparable to cotton) for textile applications. The Shirley Analyzer (SDL America, Charlotte, NC) shortened flax fibers and separated foreign matter and coarse fibers from the finer fibers. Fine fiber yield was the percent of fine fiber separated from the Flax-PP-cleaned fiber. Shirley-cleaned fibers were analyzed for strength and elongation using a Stelometer, based on the methods developed for cotton (3). They were also analyzed for fineness using air flow, based on the micronaire method (4) that was modified for flax by Akin et al. (1).

The data were statistically analyzed with the general linear models procedure in SAS (SAS Institue Inc., Cary, NC) using Duncan's new multiple range test ($P < 0.05$) to detect differences between means.

Evaluation of Tillage and Subsoiling

Datasets were tested for homogeneity of variance using HovTest = Levene option in SAS and found homogenous except for kg cotton lint/ha, cotton plants per plant row, cotton fiber elongation, and flax fiber fineness. Differences for the fiber properties and yield existed between years for both crops, but year × tillage interactions were not significant for any variable. Therefore, data presented are averaged over years with the exception of heterogeneous variables which are presented for each year.

Subsoiling

Across all tillage treatments, subsoiling did not affect fiber length, length uniformity, strength, or micronaire (Table 1). For all homogeneous and heterogeneous variables in this study, a subsoil × tillage treatment interaction ($\alpha = 0.05$) occurred only for the measurement of yellowness (+b). Since cotton was saw-ginned on a laboratory-scale gin, color measurements from these gins do not relate well to commercially ginned lint and should not be evaluated. Subsoiling main effect was significant ($\alpha = 0.05$) for one heterogeneous variable (lint yield) in the first year of the study. Across all tillage treatments, subsoiling increased cotton lint yield by 135 kg/ha in 2001 and 127 kg/ha in 2002 (Table 2). Subsoiling main effect was significant (α = 0.1) for two homogeneous variables (flax straw yield and Flax-PP yield). Across all tillage treatments, subsoiling increased flax straw yield by 447 kg/ha (Table 3). Subsoiling also increased the Flax-PP fiber yield (24% for subsoiled vs. 22% for not subsoiled). Flax-PP yield was the percent of straw processed through Flax-PP; it was not based on straw per acre. Yearly subsoiling is typically recommended for many crops on Coastal Plain soils (26) to alleviate high soil strength and provide increased crop yields (16).

Table 1. Cotton fiber quality as affected by tillage and subsoiling. Data are averaged over two years.

		Length (mm)	**Uniformity** (%)	**Strength** (g/tex)	**Micro-naire**	**Reflect-ance** (Rd)	**Yellow-ness** (+b)	**Price**[z] ($/kg)
Tillage[x]	Chisel	28.4 a	83.3 a	29.7 a	4.3 b	66.8 a	7.2 a,b	1.20
	Disk	28.0 b	82.8 b	29.8 a	4.5 a	67.7 a	7.6 a	1.20
	No-till	28.4 a	83.4 a	29.6 a	4.4 a	68.8 a	7.1 b	1.20
Subsoil[y]	Yes	28.3 A	83.2 B	29.5 A	4.4 A	67.6 A	7.4 A	1.20
	No	28.2 A	83.2 B	29.9 A	4.4 A	66.5 B	7.2 A	1.20

[x] Tillage mean values followed by different lower case letters within columns are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

[y] Subsoil mean values followed by different capital letters, within columns, are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

[z] Prospective prices of cotton lint based on current base quality using the Daily Spot Cotton Quotations to locate premiums or discounts for the southeast (27).

Table 2. Cotton yield and fiber quality as affected by tillage and subsoiling. Data are presented for two years.

		Lint (kg/ha)		**Plants per plant row** (plants per 1 m of row)		**Elongation** (%)	
		2001	**2002**	**2001**	**2002**	**2001**	**2002**
Tillage[x]	Chisel	1115 a	944 a	12.7 a	7.1b	8.5 a	8.5 a
	Disk	1133 a	866 a	12.0a,b	8.3a,b	8.0 b	8.5 a
	No-till	1089 a	966 a	11.3b	9.5a	8.1 b	8.5 a
Subsoil[y]	Yes	1180 A	989 A	12.1A	8.1A	8.2 A	8.6 A
	No	1045 B	862 A	12.0A	8.5A	8.2 A	8.4 A

[x] Tillage mean values followed by different lower case letters within columns are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

[y] Subsoil mean values followed by different capital letters, within columns, are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

Table 3. Flax yield and fiber quality as affected by tillage and subsoiling. Data are averaged over two years.*

		Dry yield (kg/ha)	Flax-PP yield (%)	Fine fiber yield (%)	Strength (g/tex)	Fineness
Tillage[x]	Chisel	1962a,b	23.0 a	22.0 a	36.3a	4.7 a
	Disk	2306a	22.1 a	24.6 a	34.7a,b	4.6 a
	No-till	1559b	23.8 a	22.4 a	33.1b	4.6 a
Subsoil[y]	Yes	2166A	24.0 A	22.5 A	34.7A	4.7 A
	No	1719B	22.0 B	23.5 A	34.7A	4.6 A

[x] Tillage mean values followed by different lower case letters within columns are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

[y] Subsoil mean values followed by different capital letters, within columns, are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

Tillage

Cotton fiber elongation (2002), and kg of cotton per ha (2001 and 2002) were not influenced by tillage treatment. Cotton plant population, cotton fiber length, length uniformity, yellowness, and micronaire significantly varied at the 0.05 level among the three surface tillage techniques. Micronaire values were lower for cotton produced with CD2H (4.3) than with D2H (4.5) or NT (4.4) treatments. Cotton micronaire was lower for CD2H indicating a finer and more desirable fiber. Regardless of differences, these mean micronaire values relate to upland base quality with no premium or discount. In this study, cotton fiber length from NT cotton was comparable to CD2H but was longer than D2H. NT demonstrated better fiber length uniformity than D2H. A higher fiber length uniformity result from no-tillage systems agrees with work performed by Bauer and Frederick (6). Cotton fiber length and length uniformity measurements command premiums that do not differ between management practices. No differences were detected for reflectance, elongation (2001), or strength of cotton fiber. The strength of cotton fibers command premiums that do not differ between management practices. In the current market, prospective cotton prices based on fiber quality do not appear to be affected by the crop management system (Table 1).

The tillage systems effect on the flax fiber crop production and the physical properties of fibers are shown in Tables 3 and 4. Flax dry plant matter yield was greater for the CD2H and D2H than for NT. This difference in dry plant matter yield did not correlate to increased Flax-PP fiber yields nor increased fine fiber yields from passage through a Shirley Analyzer. Fine fiber yield was also the percent of fine fiber separated from the Flax-PP cleaned fiber and was not based on straw per acre. NT produced a lower fiber flax stalk yield which may have been due to reduced plant populations. Flax straw yields for this study were low compared with other data (15,21).

Table 4. Flax fiber quality as affected by tillage and subsoiling. Data are presented for two years.

		Elongation (%)	
		2001	**2002**
Tillage[x]	Chisel	1.4 a	1.5 a
	Disk	1.3 a	1.2 b
	No-till	1.3 a	1.3 b
Subsoil[y]	Subsoil	1.3 A	1.4 A
	No	1.3 A	1.4 A

[x] Tillage mean values followed by different lower case letters within columns are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

[y] Subsoil mean values followed by different capital letters, within columns, are significantly different, $P < 0.05$, according to Duncan's New Multiple Range Test.

Elevated flax plant biomass levels tended to create coarse flax fibers (r = 0.49), likely as stem diameter concurrently increased (Fig. 1). As indicated by Elhaak et al. (14), increases in the percentages of α- and hemi-cellulose in flax fibers lead to improved spinnability and fiber strength. They further state that water-deficit stress could lead to increased deposition of lignin and pectin in plant stems and reduced fiber strength. Flax has been reported to demonstrate greater water use efficiency under NT relative to CT (18). Fiber strength was the only measured flax physical property that differed among the three tillage systems. Flax fiber strength was improved and greater for CD2H than NT, potentially suggesting the quality of fiber is influenced by tillage practices under the soil and growing conditions tested. However, other conditions could have contributed to fiber strength reductions such as Couture et al. (11) who demonstrated that RT leads to shorter plants with less biomass, producing fewer and shorter fibers. Dew retting was performed on identical soil surfaces for tillage treatments with differential retting not likely causing differences in this study. In this study, increased flax plant biomass levels tended to create fibers with an increased strength (r = 0.62) (Fig. 2).

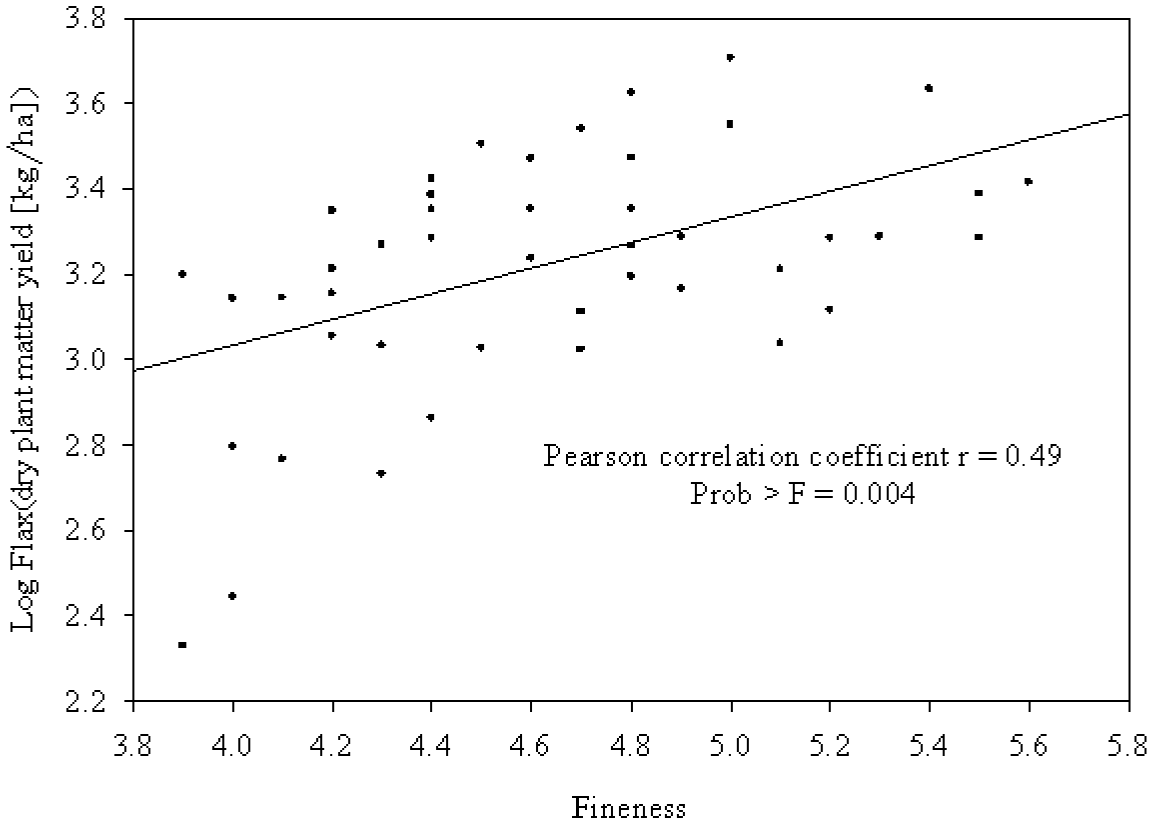

Fig. 1. Relationship between straw yield and flax fiber fineness at Florence, SC. Data are plot observations, and data from both years are included.

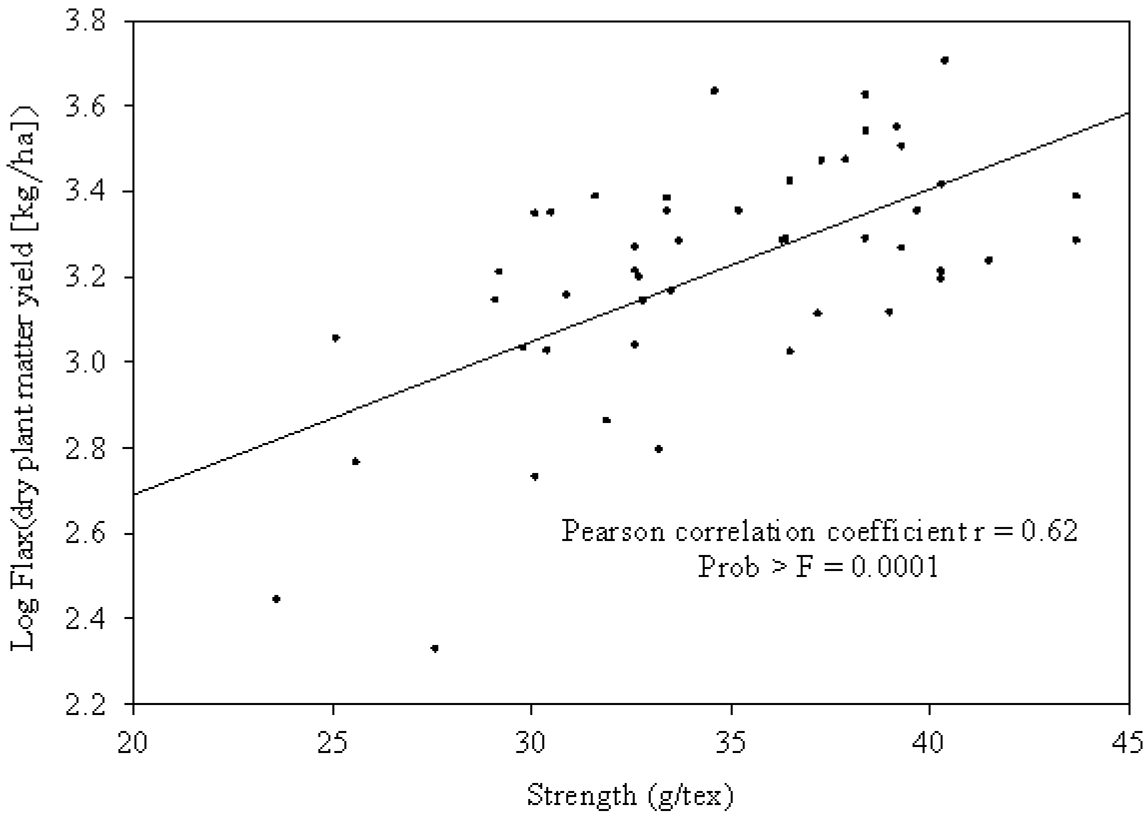

Fig. 2. Relationship between flax straw yield and fiber strength at Florence, SC. Data are plot observations, and data from both years are included.

Summary

Double-cropping winter small grains with summer crops and conservation tillage is common throughout the southeast USA. For double cropping flax with cotton we found: (i) subsoiling increased cotton and flax yields which was similar to findings for other crops; (ii) cotton yields were not influenced by tillage treatment while flax dry plant matter yields for D2H were greater than NT; (iii) micronaire, fiber length, and fiber length uniformity of cotton along with flax fiber strength were the fiber properties impacted by tillage; and (iv) flax straw yield was positively correlated with fiber coarseness and with fiber strength. Conservation tillage is widely used for cotton and these findings support its use in this double crop system. However, since CD2H and D2H increased flax yield (over NT) and provided improved fiber properties, it appears that a further characterization of flax fiber quality and a detailed analysis of conservation management is required for more reliable management of fiber flax production in this system. In this study, the prospective price of cotton under diverse management systems is currently not different using Daily Spot Quotations but small cotton fiber quality improvements may aid in the export market with higher market prices increasing differentiation.

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